B-52.2 Studies on the effects of global warming on forest/grassland in China and the conservation of vegetation

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Abstract

To study the effects of "global warming" on forest/grassland in China, we collected data of vegetation, climate, etc. and seeds of some tree species commonly grown in China. Using climate data and MRI-CGCM-global warming scenario (1% CO_2 increase/year during the coming 100 years), it predicted that annual mean temperature, Warmth Index and Effective Accumulated Temperature in China would increase, and the increase ratio would be greater in north area than in south. Global warming also would slightly promote the aridity in China. Experiments on the effects of global warming on growth of 4 main Chinese tree species were conducted using environment-controlled growth cabinets. Temperature higher than *c.*30℃ decreased the growth of all species examined, especially, *Cunninghamia lanceolata*. Dry condition (low RH) restricted the growth of *Pinus massoniana*. Growth analysis revealed that the reduction of RGR caused by heat-stress or water-deficient stress was due to a reduction of NAR, however, the partitioning of photosynthate was hardly affected. It suggested that global warming would change the distribution of tree species in forest of China in the future.

Key Words China, Environment changes, Forest/grassland, Global warming, Growth

1. Introduction

Increase in the concentration of CO_2, one of the global warming gas, can cause considerable effects on vegetation itself and on some important environment factors related to plant growth, such as increasing temperature, changing precipitation, etc. In some areas, the promotion of aridity has also been anticipated and the effects on vegetation have been attracting public concerns. Although a huge forest/grassland existed in China, the decline/degradation of vegetation caused by land use change and pollution has already become one of the most severe environmental problems (C.E.C., 1998). It is anticipated that the environmental changes accompanied by global warming will bring more stresses to the vegetation in the future. In order to clarify the effect of global warming on productivity and distribution of a regional vegetation and to support its conservation, it is necessary to promote the collection and integration of the basic data from experimental researches, field surveys, etc. and to promote the simulation and prediction researches.

2. Research Objective

The aim of this research is to predict the effects of environmental changes accompanied by global warming on the productivity and distribution of forest/grassland in China and to collect/integrate the knowledge that contributes to the conservation of regional vegetation. Therefore, we constructed the collaboration system with some research institutes in China and collected and analyzed various data related to vegetation and environment/meteorology in China. Then, we predicted the effects of global warming on phytoclimate/agroclimate using the global warming scenario in China resulted from the General Circulation Models (GCM). In addition, we conducted some field surveys, collected seeds of the main tree species in China and conducted some model experiments related to interspecific competition and environmental adaptation of these species, using environment-controlled growth cabinets (Phytotron). By the aforementioned approaches, we analyzed and predicted the effects of global warming on productivity and distribution of regional vegetation in China in the next century.

3. The prediction of the effects of global warming on phytoclimate/agroclimate in China

IPCC report (1995) predicted that the increase in temperature would be about 2.0-3.0℃ at the end of the coming century. However, the degree of warming would change by latitude and longitude from the results of many GCMs. In this study, we used the warming scenario of MRI-CGCM developed in Meteorological Research Institute in Japan. Using climate data in China and GCM-warming scenario, we predicted the effects of global warming on phytoclimate and agroclimate in China.

Research Methods

General Circulation Model (MRI-CGCM)

The details of MRI-CGCM used in this research was reported by Tokioka et al. (1995), and the scenario of the output from the model has been presented as CD-ROM (Vol. 1, 2). We used the scenario values (under the assumption that the CO_2 concentration increases at an annual rate of 1% in the coming 100 years) such as monthly mean temperature, monthly precipitation, monthly mean evapotranspiration from ground level and short wave radiation downward, of grid points which distributed in lat.18-50N. and long.90-130E. Naturally, climate change modifies regional weather condition and subsequently affects natural vegetation, crops and human society. In this study, monthly meteorological parameters of each grid point covered almost all China were utilized.

Evaluation of phytoclimate and agroclimate

The productivity and the distribution of natural and crop vegetation are closely related to the regional climate-phytoclimate resources in each area. The richness of phytoclimate resources can be evaluated by "temperature" and "water supply". In this study, two climate indexes widely utilized for the quantitative evaluation of the temperature resource in the field of plant ecology and agriculture ecology were used from the viewpoint of effect of global warming on the regional temperature resources (Yim & Kira, 1975; Fang & Yoda, 1988; Uchijima et al, 1992).

○Warmth Index (WI: ℃·month) $= \Sigma(T_i - 5) \quad T_i \geqq 5℃$ (1)

○Effective Accumulated Temperature (ΣT_{10}: ℃·day) $= \Sigma(T_j) \quad T_j \geqq 10℃$ (2)

where, T_i: monthly mean temperature (℃); T_j: daily mean temperature (℃).

Two climate indexes were used for evaluating capacity of water supply (Uchijima & Seino, 1985; Ohta et al, 1993).

○Radiative Dryness Index (RDI) $= Rn/l \cdot r$ (3)

○Aridity (Humidity) Index (K) $= P/(WI+20) \quad 0 < WI < 100$ (4)

$= 2P/(WI+140) \quad 100 \leqq WI < 200$ (4')

where, Rn: annual net radiation (kcal/cm^2); l: latent heat of evaporation (0.581kcal/gH_2O); r: annual precipitation (cm); P: annual precipitation (mm); WI: Warmth Index.

The meteorological data of the mean values from 1961-1990 in China were analyzed and utilized in order to calculate each climate index.

Results and Discussion

Effects of global warming on the annual mean air temperature in China

Under the assumption that the CO_2 concentration increases at an annual rate of 1%, MRI-CGCM predicted that the average global temperature would rise continuously and the possibility of warming would be 2.0-2.5℃ at 100 years later. This is almost correspondent to IPCC report (1995). The mean annual precipitation would also increase *c.* 70mm with the reflection of the increase in the vapor capacity resulted from temperature increase. However, it is anticipated that the degree of warming would change from region to region. Therefore, the increase in annual mean temperature in each grid point was examined using the global warming scenario and control one (present climate). Current study predicted clearly that the annual mean temperature would increase systematically in China. The amount of temperature increase would reach 4-5℃ in some mountain and highlands regions in the north and west of China where the present temperature is low. While, in the south with subtropical climate, the increase in annual mean temperature would be *c.* 2-3℃. The regional change of such temperature increase could be estimated by the following equation.

$$T_{100} = 4.6 + 0.935\ T_{con} \qquad (5)$$

where, T_{100}: annual mean temperature (℃) at 100 years later in a global warming scenario; T_{con}: annual mean temperature (℃) in a control scenario.

Effects of global warming on the "Warmth Index" in China

The changes in phytoclimate and agroclimate resources were studied using a global warming scenario at 100 years later. To clarify how phytoclimate would respond regionally to the global warming, we evaluated the change in Warmth Index (WI) as the change in temperature resources, which influences geographical distribution of natural vegetation. It was estimated that the WI would drastically increase, and the increase in WI by the warming was estimated by the following equation.

$$WI_{100} = 23.0 + 1.015\ WI_{con} \qquad (6)$$

where, WI_{100}: Warmth Index (℃·months) at 100 years later in a global warming scenario; WI_{con}: Warmth Index (℃·months) in a control scenario.

The distribution maps of WI under the control scenario (present climate) and under the warming scenario (100 years later with 1% CO_2 increase/year) are shown in Fig. 1. The increase in the WI by the warming would be *c.* 50% in cold region to *c.* 10% in subtropical zone, and an absolute amount would increase to *c.* 24℃·months and *c.* 28℃·months, respectively. In the cold area of north China where WI_{con} is lower than 100℃·months, it was shown that the natural vegetation possibly would move drastically northward with the warming. However, it is known from fossil pollen analysis during 10-15 thousand years in postglacial age that the migration of natural tree species was considerably slower than that of climatic zone. Therefore, it is questioned whether the natural vegetation can sufficiently follow the migration of the climatic zone brought artificially during the coming 100 years.

Effects of global warming on the "Effective Accumulated Temperature" in China

Cultivation bands of main crops change with the change of Effective Accumulated Temperature (ΣT_{10}: ℃·days). It was predicted that ΣT_{10} would increase considerably in whole China by the warming. It was shown by the next approximation.

$$\Sigma T_{10,\,100} = 840 + 1.017\ \Sigma T_{10,\,con} \qquad (7)$$

where, $\Sigma T_{10,\,100}$ (℃·days): ΣT_{10} at 100 years later in a global warming scenario; $\Sigma T_{10,\,con}$ (℃·days): ΣT_{10} in a control scenario.

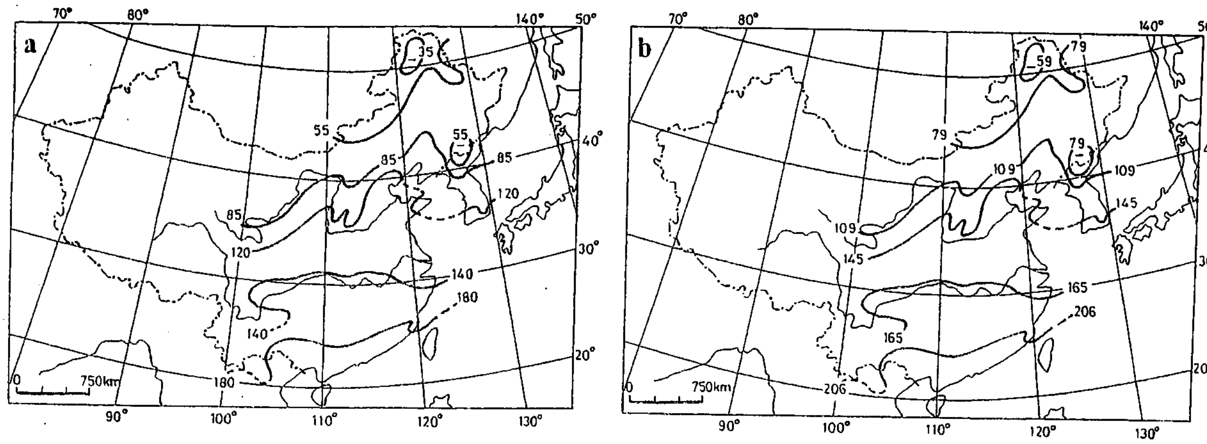

Fig. 1. The distribution of Warmth Index (WI) in China, a: control scenario (present climate); b: global warming scenario (100 years later with 1% CO_2 increase/year).

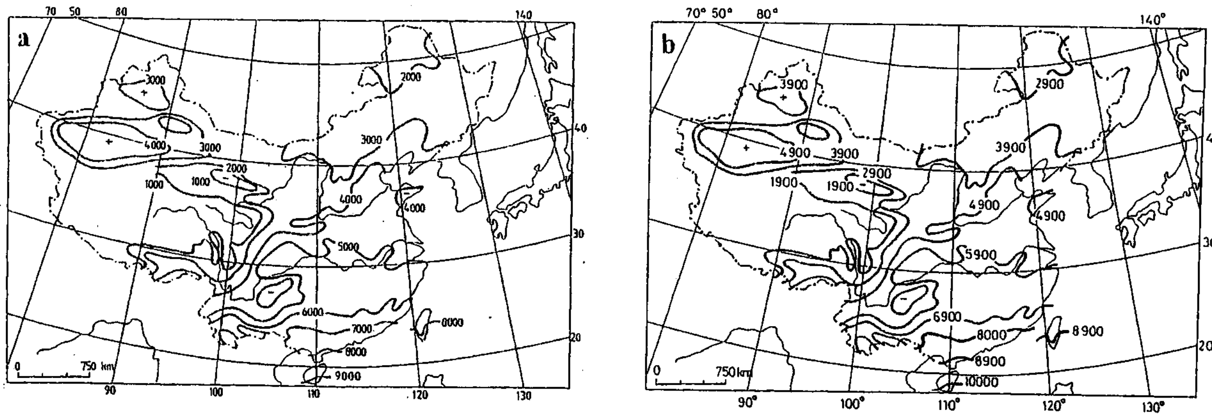

Fig. 2. The distribution of Effective Accumulated Temperature (ΣT_{10}) in China, a: control scenario; b: global warming scenario.

The distribution maps of ΣT_{10} under the control scenario and under the warming scenario are shown in Fig. 2. The ΣT_{10} would increase from 30-40% in north and west highlands region to 10-12% in subtropical zone in south coast.

The absolute amount of the increase in ΣT_{10} would be from *c.* 900 in the north to *c.* 1000 in the south. In north-northeast China with lower value than 5000℃·days of $\Sigma T_{10, con}$, $\Sigma T_{10, 100}$ would increase in 20-40% at the end of 21^{st} century. It was anticipated that crop cultivation band would migrate northward drastically and that the frequency of cool summer damage should decrease in these areas where the damage is so severe at present.

Effects of global warming on the latitude-distribution of temperature resources in eastern monsoon region, China

In the eastern monsoon region in China, eastward from long.105-110E., the temperature resource decreases exponentially with the increase in the latitude. Using the global warming scenario and control scenario from MRI-CGCM, we have simulated how the warming period would affect the exponential change of the temperature resources to the latitude (Fig. 3). The warmth index exponentially decreases with the increase in the latitude, and this curve pattern would move parallel to the upper part. This relation was approximated by the exponential function.

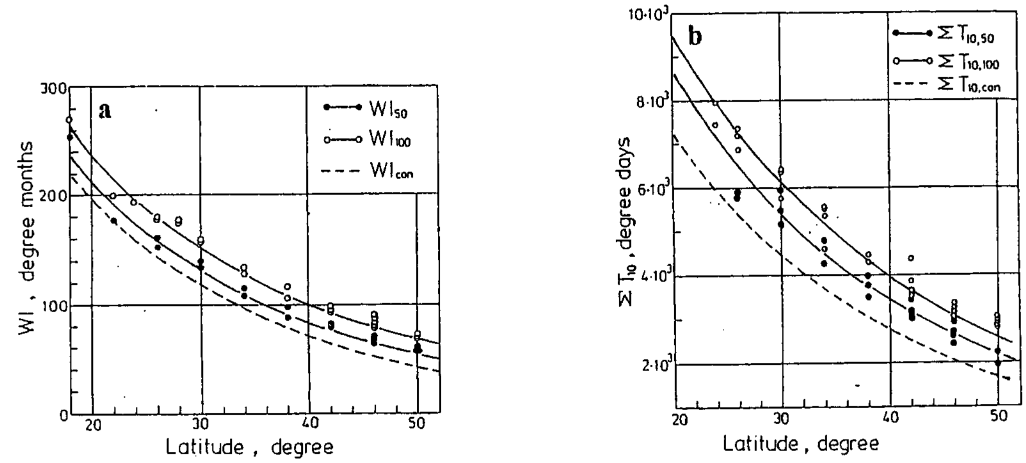

Fig. 3. Effects of global warming on a: WI-latitude relation, b: ΣT_{10}-latitude relation, in east monsoon region of China.

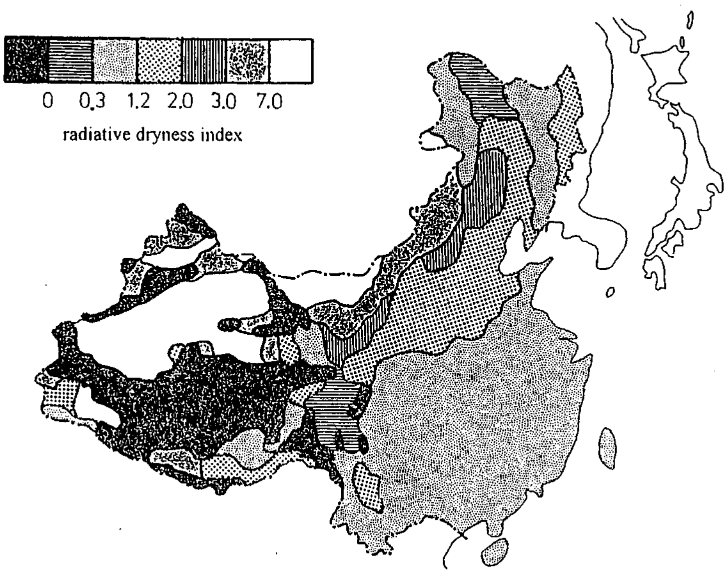

Fig. 4. Distribution Map of RDI in China.

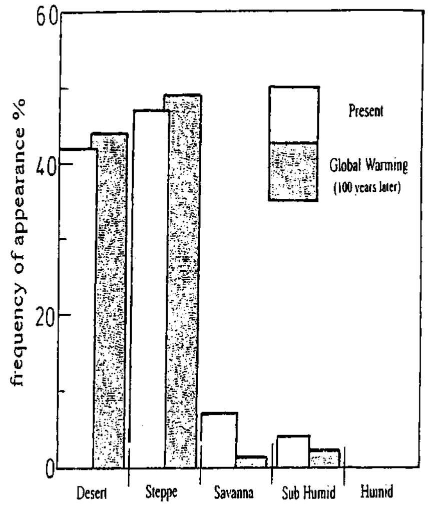

Fig.5. Effects of global warming on Aridity Index (K).

$$
\begin{aligned}
&\text{Control:} && WI_{con} = 220\ \mathrm{Exp}\ [-\ 0.049\ (X\text{-}18)] \\
&\text{Warming period, 50 years:} && WI_{50} = 240\ \mathrm{Exp}\ [-\ 0.046\ (X\text{-}18)] \\
&\text{Warming period, 100 years:} && WI_{100} = 270\ \mathrm{Exp}\ [-\ 0.043\ (X\text{-}18)]
\end{aligned} \tag{8}
$$

Similarly as WI, ΣT_{10} decreases exponentially with the increase in the latitude, and the curve of relationship between ΣT_{10} and latitude would move parallel to the upper part with the warming period. This relation was also approximated by the exponential function.

$$
\begin{aligned}
&\text{Control:} && \Sigma T_{10,\,con} = 8000\ \mathrm{Exp}\ [-\ 0.044\ (X\text{-}18)] \\
&\text{Warming period, 50 years:} && \Sigma T_{10,\,50} = 9000\ \mathrm{Exp}\ [-\ 0.044\ (X\text{-}18)] \\
&\text{Warming period, 100 years:} && \Sigma T_{10,\,100} = 10000\ \mathrm{Exp}\ [-\ 0.044\ (X\text{-}18)]
\end{aligned} \tag{9}
$$

It was predicted that the isoline of ΣT_{10} would migrate northward, and the migration would be more in north plateau (900km) than south seacoast (600km). This would result in the migration and change in agriculture band in the eastern monsoon region in China.

Distribution of Dryness Index and Effects of global warming

By using Radiative Dryness Index (RDI) calculated from the meteorological data, the RDI distribution map in China was drawn (Fig. 3). East area from long.105E. belongs to eastern monsoon region, except for Inner Mongolia. In south area from Huanghe (Yellow) River, the humid/subhumid area ($0.3<RDI<1.2$) distributes. From the coast (east) to the inland (west), the dryness increases gradually, and dry area ($2.0<RDI<7.0$) exists in Inner Mongolia. Forests distribute in humid/subhumid area, and with the richness of the temperature resources, evergreen forest, deciduous broad-leaved forest and coniferous forest distribute from the south to the north. In south area from Changjiang (Yangtze) River, subtropical forests distribute. In west area from long.105E., negative RDI area, dry climate area ($2.0<RDI<7.0$) and desert climate area ($RDI>7.0$) distribute. In these regions, temperature/water resources are extremely limited, and the natural vegetation is very poor.

As there was no net radiation data in the MRI-CGCM-scenario in this study, we calculated the Aridity/Humidity Index (K) from WI and annual precipitation, and compared between warming and control scenarios. In the warming scenario relative to control one, it was estimated that the proportion of desert ($K \leqq 3$) and grassland ($3 \leqq K \leqq 5$) climates would increase and that the proportion of savanna ($5 \leqq K \leqq 7$) and semi-humid ($7 \leqq K \leqq 10$) climates would decrease, slightly. In China continent, the aridity might be comparatively promoted, though a mean annual precipitation would be increased by the warming. The water environment is one of the most important factors for plants. Therefore, to predict the aridity-promoted area accompanied by global warming, it need to collect/integrate more detailed meteorological/environmental data and to develop more precise regional model.

4. Effects of global warming on the growth of several Chinese tree species

Though there are so many reports related to the effects of global warming on the growth of crops and grasses, species of natural vegetation such as tree species have been seldom examined (Wong, 1993; Gallaway et al, 1994; Imai and Kanda, 1995; Eamus et al, 1995). So far, there is almost no experimental research on the effects of environmental changes on Chinese tree species (Zhang, 1996). In the present study, we conducted the experimental examination using environment-controlled growth cabinets in order to obtain some basic data on the effects of global warming on the growth of forest tree species in China.

Research Methods

Cooperation with Chinese Institutes and collection of references, data and tree seeds

In this study, in order to integrate the knowledge that contributes to conserve a regional forest/grasslands in China, we have contacted several institutes such as Institute of Botany, Chengdu Institute of Biology, Environment Protection Bureau of Sichuan Province, etc. Then, we constructed the researchers network for collaboration, and collected research references and regional meteorological, environmental, biological and ecological data. We also conducted field surveys and collected seeds of some species around the Minjiang River (a branch of Changjiang River) and it's upstream area around an institute's field station. These seeds first air-dried in the field station and brought back to Japan legally, then preserved in a cold room (4℃) before experiments. We selected four tree species such as *Pinus massoniana* Lamb., *Pinus tabulaeformis* Carr, *Platycladus orientalis* (Linn.) Franco cv. *Sieboldii* and *Cunninghamia lanceolata* (Lamb.) Hook as experimental materials because of their high germination and growth rates. These are main forest composition species in China and distributed not only in Sichuan Province, but also in wide areas of China (Delectis Florae R.P.S. Agendae Academiae Sinicae Edita, 1978). The area percentage (to the whole forest land in China) of each tree species is 13.2% (*P. massoniana*), 2.5% (*P. tabulaeformis*), 1.7% (*P. orientalis*) and 8.4% (*C. lanceolata*), respectively (Li and Li: 1996).

Experiments of effects of heat stress and water-deficit stress on Chinese tree species

After washing mildly, seeds of each species were sown on artificial soil in an greenhouse controlled at 25℃, 75%RH. Seedlings with height *c*. 5-10cm were transplanted into pots containing standard artificial soil and grown in the same greenhouse, supplied with 0.1% Hyponex solution with Hoagland's No. 2 microelement plus 142 μM Fe (Ⅲ) EDTA. When these juvenile trees became 10-20cm in height, they were transferred to four artificially lighted environment-controlled growth cabinets (KG-50 HLA-D; KOITO) for the growth experiment. After the experiment, each plant was divided into leaf, stem and root, oven-dried at 80℃ for 3days or more and weighed each dried organ. Using growth analysis method, growth parameters such as Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Weight Ratio (LWR), Stem Weight Ratio (SWR), Root Weight Ratio (RWR) were calculated, and effects were compared. In this experiment, as all species were conifers, we have not measured leaf area. However, NAR was also calculated as an amount of increase in individual dry weight per leaf dry weight.

<u>Experiment 1: temperature-growth response</u>

Environmental conditions in the cabinets of this heat-stress experiment were: Light/Dark period, 14/10hr; light intensity, 600μE·$m^{-2}sec^{-1}$ at canopy levels; Relative Humidity (Light/Dark), 70/80%; CO_2 concentration, 400ppm for all cabinets. Air temperature (Light/Dark), 25/18; 29/22; 33/26 and 37/30℃ for each cabinet, respectively. The growth experiment was carried out for 4 weeks.

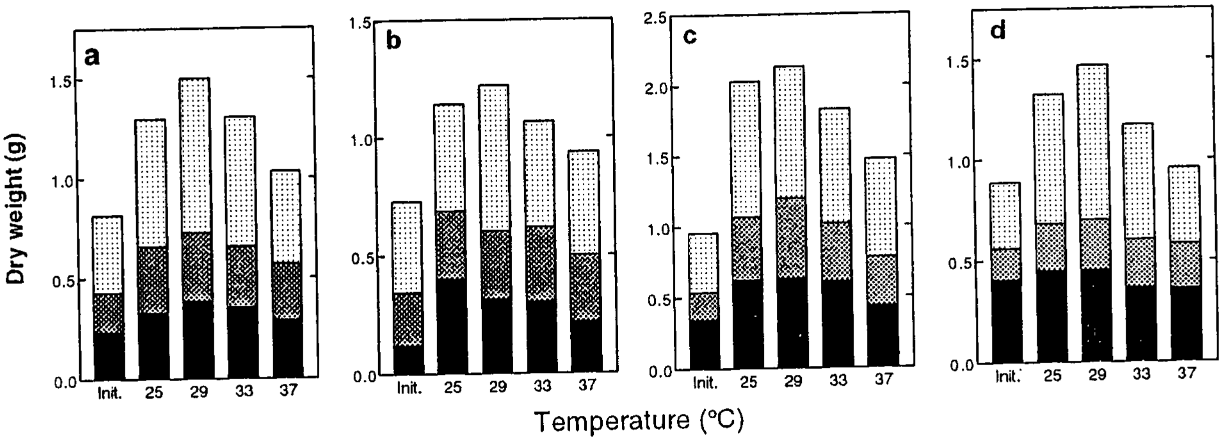

Fig. 6. Effect of temperature increase on the dry weight growth, a: *P. massoniana*, b: *P. tabulaeformis*, c: *P. orientalis*, d: *C. lanceolata*. (▒: Leaf, ▓: Stem, ■: Root)

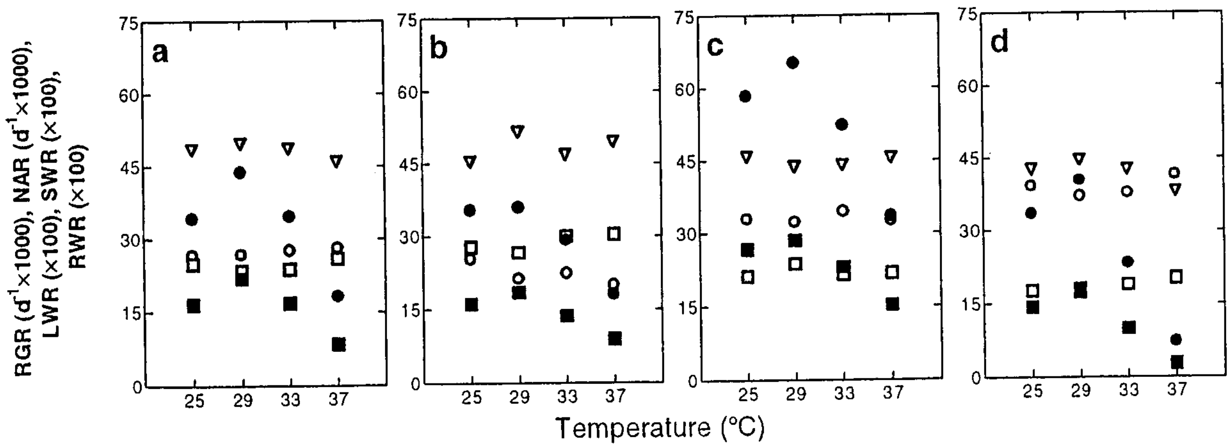

Fig. 7. Effect of temperature increase on the growth parameters, a: *P. massoniana*, b: *P. tabulaeformis*, c: *P. orientalis*, d: *C. lanceolata*. (■: RGR, ●: NAR, ▽: LWR, □: SWR, ○:RWR)

Experiment 2: relative humidity-growth response

Environmental conditions in the cabinets of this water deficit-stress experiment were: Light/Dark period, 14/10hr; light intensity, 600μE·$m^{-2}sec^{-1}$ at canopy levels; Air temperature (Light/Dark), 29/22℃; CO_2 concentration, 400ppm for all cabinets. Relative Humidity (Light/Dark), 40/50%; 50/60%; 60/70% and 70/80% for each cabinet, respectively. The growth experiment was carried out for 4 weeks.

Results and Discussion

Effects of temperature increase on the growth of Chinese tree species

Individual (each organ) dry weight of Chinese tree species grown for 4 weeks under the temperature in light period as set at 25, 29, 33, 37℃ is shown in Fig. 6. The response of each tree species to temperature was almost similar. They could grow best at 29℃, and growth of all species reduced with increasing in temperature. However, the degree of growth reduction caused by temperature increase was different from species to species. The most remarkable effect was found in *C. lanceolata* as compared with *P. massoniana*, *P. tabulaeformis* and *P. orientalis*.

The growth parameters were calculated and compared on the basis of this dry weight

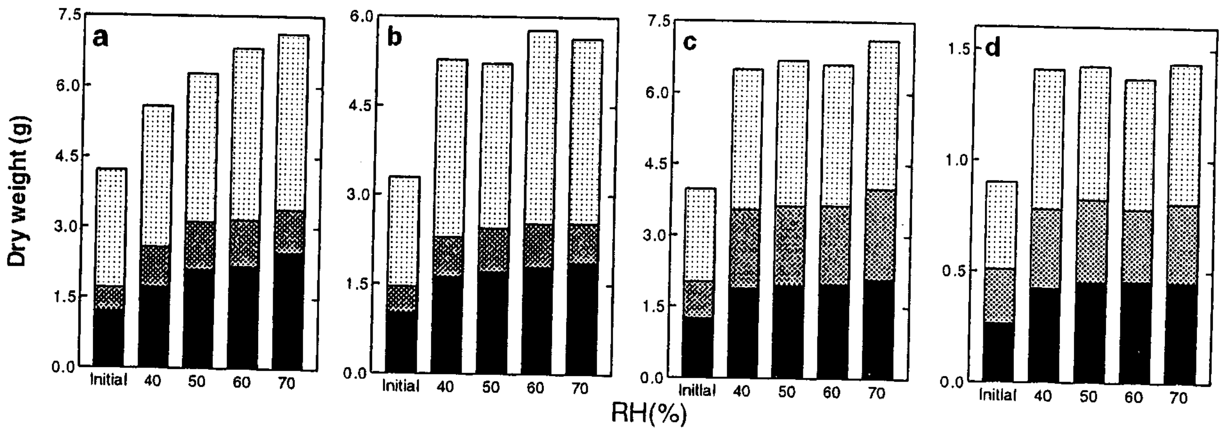

Fig. 8. Effect of relative humidity on the dry weight growth. a: *P. massoniana*, b: *P. tabulaeformis*, c: *P. orientalis*, d: *C. lanceolata*. (▒: Leaf, ▓: Stem, ■: Root)

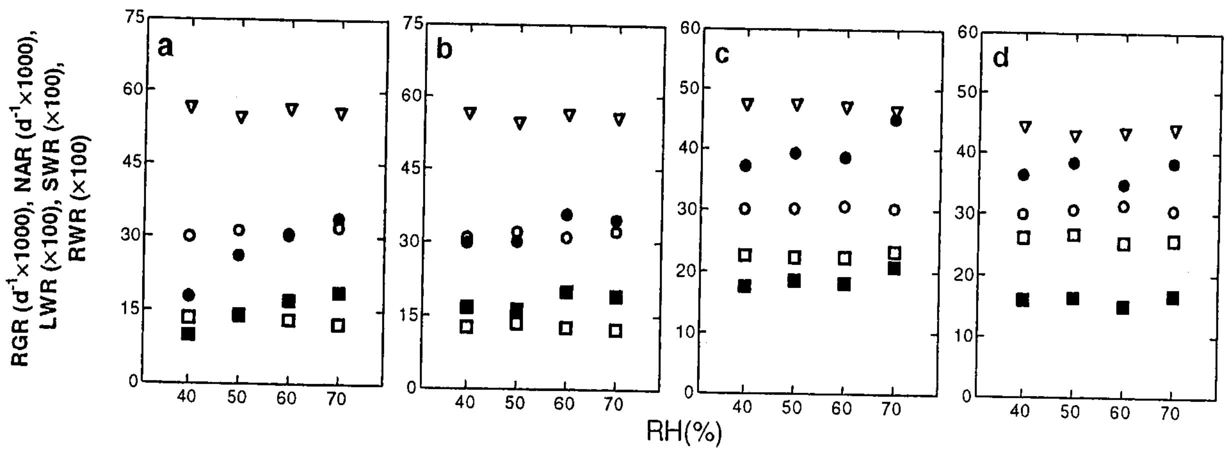

Fig. 9. Effect of relative humidity on growth parameters of Chinese tree species. a: *P. massoniana*, b: *P. tabulaeformis*, c: *P. orientalis*, d: *C. lanceolata*. (■: RGR, ●: NAR, ▽: LWR, □: SWR, ○:RWR)

data (Fig. 7). In comparison with the 29℃ treatment, RGR of plant in the 37℃ treatment was suppressed by about 50% in the case of *P. massoniana*, *P. tabulaeformis* and *P. orientalis*. In the meantime, there was a remarkable effect of the temperature increase on RGR of *C. lanceolata,* suppressed by about 85%. Temperature effect on NAR was almost similar to the effect on RGR. As a result of comparing LWR, SWR and RWR, there was almost no remarkable effect of temperature on these values in all species. It indicated that the effect of temperature increase on RGR might due to the effect on NAR originally. In this experiment, LWR, SWR and RWR were hardly affected the temperature increase did not seem to cause a remarkable effect on the partitioning of photosynthate in these trees.

Effects of relative humidity on the growth of Chinese tree species

The individual (each organ) dry weight of Chinese tree species grown for 4 weeks under the relative humidity in light period of 40, 50, 60, 70% RH is shown in Fig. 8. In the case of *P. massoniana*, dry weight growth was the highest at 70% RH, and the growth was suppressed with lowering of relative humidity. As compared with *P. massoniana*, however, other 3 species as *P. tabulaeformis*, *P. orientalis* and *C. lanceolata* were tended to be slightly suppressed in the growth with the lowering of relative humidity.

The growth parameters were calculated and compared on the basis of these dry weight data (Fig. 9). In comparison with the 70% RH treatment, RGR of *P. massoniana* with the 40% RH treatment was suppressed by about 50%, whereas suppressed by about 15% in *P. tabulaeformis* and *P. orientalis* and by only 5% or so in *C. lanceolata*. Only *P. massoniana* was remarkably sensitive to lowering relative humidity. On the effect of the relative humidity on NAR, it was almost similar to the effect on RGR. There was almost no remarkable effect of relative humidity on LWR, SWR and RWR in all species. It indicated that the effect of relative humidity on RGR might due to the effect on NAR. As a result of comparing LWR, SWR and RWR, relative humidity did not seem to cause a remarkable effect on the partitioning of photosynthate in these tree species (Shimizu et al, 1996).

C. lanceolata which was sensitive to high temperature in the present experiment occupies 8.4% of all forest area in China, and *P. massoniana* which was sensitive to water stress occupies 13.2% of all forest area in China (Li & Li: 1996), therefore, environmental changes accompanied with global warming seemed to affect not only on the growth and the distribution of each species but also on the species composition of the forest in a large area that related to national and regional environmental conservation in China.

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